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TITLE: SAFEGUARDS FOR LONG-TERM MANAGEMENT OF RADIOACTIVE WASTES

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SAFEGUARDS FOR LONG-TERM MANAGEMENT OF RADIOACTIVE WASTE

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ABSTRACT

In nuclear material safeguards parlance radioactive wastes are "measured discards." However, the accumulation of large amounts of fissile materials in wastes over a period of time can be a safeguards concern like waste inventories in the US, which may contain more than 10 Mt of fissile materials. In addition to conventional radioactive waste forms, such as high-level wastes, transuranic wastes, and low-level wastes, spent nuclear fuel from commercial fuel cycles is now considered a radioactive waste form in the US. Spent nuclear fuels, placed in underground repositories, have the potential to become plutonium mines of the future and attractive targets for diversion or theft because of their valuable material content and decreasing radioactivity. In the context of present strategies for the disposal of these radioactive waste forms, this paper identifies some of the domestic and international safeguards issues relevant to the various proposed scenarios for the long-term management and permanent disposal of radioactive wastes in geologic repositories. Present knowledge of inventories is presented to illustrate the enormity of the problem of verifying special nuclear material contents of waste inventories in the US. Good materials management practices during the disposal phase of nuclear wastes should have elements to address issues that are identified here.

I. INTRODUCTION

Radioactive waste management has been a smoldering issue for decades. During the last decade, the problem of nuclear waste and the public's perception of the problem became a significant issue worldwide, and there is now a sense of urgency about the long-term management of such wastes. In response to this urgency, industrialized nations have established a variety of programs to develop strategies and technologies to manage radioactive wastes from womb to tomb. After decades of benign neglect, the issue of nuclear waste management seems to be receiving the attention it deserves. Although radioactive wastes have been accumulating in the US for half a century, only during the last two decades have there been concerted efforts at addressing problems. Presently, there are well established programs in place to develop sound technological solutions for both interim and long-term management of these radioactive wastes. After considerable study and debate, the US programs were codified in a 1982 legislation—"The Nuclear Waste Policy Act of 1982" (Ref. 1). According to this legislation, it is the responsibility of the US Department of Energy (DOE) to develop strategies, systems, and technologies for the long-term isolation of all spent nuclear fuels (SNFs), high-level wastes (HLWs), and transuranic (TRU) wastes in the US. Because of the unique socio-political atmosphere surrounding radioactive waste management, there are still considerable challenges to the scientific community for developing technological solutions, including safeguards strategies, acceptable to a concerned free society.

The present US strategy for long-term management of radioactive wastes involves direct disposal of spent nuclear fuels and vitrified high-level wastes in common geologic repositories and a separate geologic repository for TRU wastes. The scenarios for long-term isolation of these waste forms in geologic repositories have distinct and unique safeguards problems, and they are quite different from those encountered in developing safeguards systems for conventional bulk-handling and item-accounting facilities.

This report identifies some of the key issues that ought to be considered in developing safeguards systems for radioactive waste materials now in US inventory and destined for eventual geologic disposal. It is hoped that the material presented here will stimulate discussions on the subject among the safeguards community and help to develop strategies and systems for safeguarding large quantities of fissile and fertile materials contained in HLWs, TRU wastes, and SNFs.

II. US WASTE INVENTORIES

Nuclear fuel cycles generate a variety of waste forms that require long-term isolation from the biosphere. In the US, both civilian and defense fuel cycles have accumulated large quantities of radioactive wastes. A summary of various radioactive waste forms in the US that require special disposal strategies are shown in Table I (Ref. 2).

Among these waste forms SNFs from commercial fuel cycles, HLWs from spent fuel reprocessing, TRU wastes from defense fuel cycles, and a variety of miscellaneous radioactive materials (MRMs) from DOE sites are of interest to nuclear material safeguards. These waste forms contain fissile and fertile materials in differing quantities, and all of them have the potential to become materials for which

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TABLE I. US Radioactive Waste Inventory at the End of 1989

Waste Form	Quantities
Spent nuclear fuels*	8 000 m^3 (or 20 000 Mt)
High-level wastes*	381 000 m^3
TRU wastes*	289 000 m^3
Miscellaneous radioactive materials* (DOE sites)**	260 Mt
Low-level wastes	3 909 000 m^3
Uranium mill tailings	117 600 000 m^3
Mixed LLW	56 000 m^3
Wastes from environmental restoration activities	10 008 000 m^3
Reactor decommissioning	254 Mt†

* Material forms that may contain significant quantities of fissile materials.

** Include nuclear fuels from test and damaged reactors, scrap, etc.

†Each commercial reactor decommissioning will generate approximately 16 000 m^3 of radioactive wastes.

safeguards should be applied. Because none of the other waste forms are known to contain any significant levels of fissile materials, this paper will not address them any further.

None of the waste forms of potential safeguards concern have had an accurate accounting of their special nuclear material (SNM) contents. Some of the reported SNM contents of various waste forms are summarized in Table II.

In the data presented in Table II, the fissile contents of spent nuclear fuels are reasonably good estimates. All the other data presented in Table II are current best estimates and will change when better estimates become available.

In addition to the above estimates, it may be possible for some of these waste forms to contain part or all of the fissile materials declared as inventory differences (IDs) at US nuclear material production facilities. Since 1977, the US Nuclear Regulatory Commission and the US DOE have been reporting the inventory differences of most of the US nuclear material production facilities in unclassified, open publications. Compilation of such data from all US commercial facilities and most defense production facilities shows that there are large quantities of fissile materials unaccounted for in their materials accountancy system. For example, the cumulative inventories of three defense production facilities reported in the open literature include over 1 Mt of plutonium and a variety of other fissile materials.[4]

TABLE II. Fissile & Fertile Materials in US Inventories of Radioactive Wastes at the End of 1989

Waste Form	Quantity of fissile materials
High-level wastes*	1.8 Mt of Pu 1.3 Mt of Np +Am
Transuranic wastes*	3.0 Mt of TRUs
Miscellaneous radioactive wastes (DOE sites)**	0.4 Mt of Pu 5.7 Mt of ^{235}U 1.3 Mt of ^{233}U
Spent nuclear fuels (Commercial)†	160 Mt of Pu 170 Mt of ^{235}U 6.4 Mt Np 7.0 Mt Am 0.3 Mt Cm

*Ref. 2.

**Ref. 2, Tables C1–C9. In addition, these waste forms are also reported to contain 178 Mt of uranium and 76 Mt of thorium.

†Ref. 3. In addition, SNF inventory has 18 700 Mt of ^{238}U.

III. SAFEGUARDS ISSUES

A. HLWs & TRU Wastes

Almost all the HLWs and TRU wastes in the US inventory have their origins in the defense fuel cycle. Data presented in Table II and reported IDs of fissile materials from defense production facilities indicate the likelihood of approximately 10 Mt of fissile materials in these waste forms. Because the total volume of these waste forms is about 700 000 m^3, it would seem a Herculean task to recover all the fissile materials in HLWs and TRU wastes employing any of the known recovery methods. However, during the last two years, there have been several proposals[5-7] to chemically isolate actinides from radioactive waste forms and transmute them to short-lived or stable nuclides. These proposals seem to suggest that recovery of fissile materials from existing radioactive waste materials is feasible and probably economically viable.

In the international safeguards arena, economic considerations (cost of SNM recovery) are not accepted as major deterrents to diversion.[6] It is assumed that all waste forms can be processed to recover SNM by some method or another, although many are not economical. Because of the declared presence of fissile materials within waste matrices, these waste forms have the potential to be diverted, and more importantly, they can become potential conduits for planned diversions within a domestic safeguards regime. There fore, it is important to design appropriate safeguards systems not only to identify the SNM contents of the HLWs and TRU wastes but to meet the requirements of domestic and international safeguards.

The HLWs and TRU wastes originating from defense production in the US are not presently subject to international safeguards. However, present plans are to place vitrified HLWs from defense production in common geologic repositories along with SNFs from commercial fuel cycles. At this location, the vitrified HLWs could enter the international safeguards regime. All spent nuclear fuels from US commercial nuclear fuel cycles have the potential to be under IAEA safeguards during interim and long-term storage and even after geologic disposal.

B. Spent Nuclear Fuels

Although spent fuels continue to be extremely radioactive for many years after they are discharged from reactors, the radioactivity level decreases considerably after several decades, and the extraction of uranium, plutonium, and a variety of other strategically valuable metals from such aged fuel becomes less hazardous. Therefore, underground repositories containing spent nuclear fuels from once-through fuel cycles have the potential to become plutonium mines in the future and are attractive targets for diversion or theft because of their valuable material content and decreasing radioactivity.

The first geologic repository in the US, as currently designed, will contain approximately 62 000 Mt of heavy metal from commercial nuclear fuels. This inventory of spent fuels will contain over 500 Mt of plutonium and a host of other fissile, fertile, and strategically important elements.[3] Decreasing energy resources, the need for raw materials for large-scale energy production, and changes in institutional and social systems, may provide incentives for future generations to recover the spent fuels from geologic repositories as valuable energy resources. Safeguards issues for this scenario need to be addressed by the international community during the development of safeguards for long-term spent fuel management.

IV. SAFEGUARDS SYSTEMS AND STRATEGIES

Systems have yet to be developed for maintaining nuclear material safeguards for SNM contained in radioactive waste materials. People in the international safeguards arena have begun thinking on the subject.[3,9,10] However, the development of strategies and systems to safeguard nuclear materials contained in radioactive waste, including spent nuclear fuels, is still in its infancy.

In the US, existing domestic safeguards systems do not specifically include nor exclude SNM contained in radioactive waste materials. However, at the present time, there are no strategies or programs designed to maintain safeguards for SNM contained in waste materials that have been accumulating for the past 50 years. First, there should be a recognition that HLWs, TRU wastes, and other miscellaneous wastes from US defense production facilities may contain approximately 10 Mt of fissile materials. Such a recognition is necessary to initiate programs to systematically examine the safeguards requirements of radioactive waste materials now in storage at DOE sites and develop both short- and long-term strategies for maintaining safeguards. Furthermore, it would be highly desirable to have such systems in place before these radioactive waste materials are processed and shipped to geologic repositories for permanent disposal.

V. CHALLENGES AND THE NEED FOR NEW APPROACHES

In a conventional safeguards regime, radioactive wastes are "measured discards." Measured discards satisfying discards criteria seldom reenter the safeguards regime. However, in the case of HLWs and TRU wastes in the US, there were no safeguards criteria for discards. Also, over the years, the SNM contents of wastes have reached rather high levels and require a reevaluation of their safeguards requirements.

During the early years of formulating international safeguards, SNFs were not considered a discardable waste form. SNFs were considered interim material forms that lent themselves to chemical processing to recover valuable fissile and fertile materials. As such, there are no guidelines to safeguard SNFs in extended long-term storage or in a geologic repository designed for permanent disposal.

Spent nuclear fuels contain SNM in large quantities. A spent pressurized water reactor (PWR) fuel assembly contains approximately 3 kg of plutonium and a spent boiling water reactor (BWR) fuel assembly contains approximately 1.2 kg of plutonium. In addition, both these SNFs contain recoverable amounts of fissile and fertile uranium and a variety of transuranics. The distribution of SNM in HLWs and TRU wastes, on the other hand, is extremely sparse. For example, assuming a uniform distribution of SNM in waste matrices, the HLWs and TRU wastes in the US contain less than 10 ppm of fissile materials. These concentrations appear rather innocuous, although the total amount (approximately 10 Mt) of fissile materials in these wastes is a very large quantity of SNM to be discarded without appropriate safeguards. The uncertainties of these reported quantities are likely to be extremely large, and there are no simple methods to verify any of these quantities. Establishing safeguards regimes for such materials in diverse matrices and numerous physical and chemical forms is extremely difficult and offers considerable challenges as well as opportunities to the safeguards community.

A. HLWs and TRU Wastes

Because the HLWs and TRU waste in the US are not presently under IAEA safeguards, only domestic safeguards are examined. The HLWs in the US are at four major locations and TRU wastes are at eight sites. Presently, these wastes are in complex matrices with a wide variety of physical and chemical characteristics. It is extremely difficult to attempt to verify the SNM contents of these waste forms by any of the known technologies. However, there is a national plan to move the stored TRU wastes to a geologic repository in a salt bed in Carlsbad, New Mexico and to vitrify all HLWs and place them in a geologic formation(s) somewhere in the continental US. These strategies allow for some simple method of verifying the SNM contents of repository packages leaving storage locations or processing facilities.

Presently, all the HLWs and TRU wastes stored in the US are at DOE facilities under protective custody. It is highly unlikely that these materials will be stolen from their present storage locations. However, movement of these waste forms for geologic emplacement may be monitored for estimating the quantities of SNM being transferred to disposal facilities, and they may be kept under containment and surveillance until they are placed in their final disposal location.

The SNM content of TRU wastes may be estimated using a variety of nondestructive assay (NDA) techniques.[11] The estimation of SNM contained in vitrified HLWs is not readily achieved by NDA techniques. However, the vitrification process requires removing stored wastes and converting them through batch processing into a calcine. It may be possible to sample these calcines in batches and get a better estimate of their SNM content through destructive analysis. Thus, there are opportunities to better estimate the SNM contents of HLWs and TRU wastes during processing and packaging for geologic placement.

B. Spent Nuclear Fuels

The SNFs in the US are under domestic safeguards and are likely to be placed under international safeguards during long-term storage and during residence in geologic repositories.

The fundamental requirement of international safeguards is to "assure" the continued presence of nuclear materials within designated boundaries. This requires establishing a system of accounting for and control of nuclear materials within spent fuels and thereby enabling both the State and international regulatory agencies to verify the safeguards system. In addition to containment and surveillance, the IAEA detects diversion of SNM contained in spent fuels by verifying the SNM contents of fuel assemblies by independent measurements and comparing these measurements with the declared values. However, such measurements are time consuming and the estimates of fissile contents usually have large uncertainties. Detailed analyses of such verification schemes using known NDA technologies show that such schemes for spent fuel assemblies cannot satisfy the requirements of present safeguards regimes for goal quantity and timeliness of detection.[3,12] Therefore an alternative to extensive measurements, such as item verification, ought to be considered for maintaining safeguards for SNM during their long-term surface storage.

Permanent geologic repository designs are meant to isolate the spent fuels from the biosphere for a long time and prevent accidental access by man. This is in direct conflict with the basic premise of international safeguards, that nuclear material can be made available for inspection at suitable intervals. Because spent nuclear fuels become attractive targets for diversion as their fission-product radioactivity decreases, it may be necessary to maintain safeguards for spent fuels for an undetermined time. IAEA's requirement to verify inventories should be reexamined and alternative methods of "assurance" should be developed. For a closed repository, it is desirable to maintain continuing assurance that spent fuel is still there. However, this may not be the most important requirement in the context of geologic disposal. What may be assuring and reasonably achievable is that spent fuel is not being brought to the surface and transferred off site. Systems designed to achieve this objective may be more appropriate to maintaining safeguards for SNFs in geologic repositories.

Safeguards for long-term retrievable storage should be different from those for geologic permanent storage. Long-term storage can range from a few years to a few decades, and possibilities of diversion from interim storage are more likely than from permanent disposal facilities. Safeguarding spent fuel dismantling/consolidation facilities is another problem that needs to be addressed and resolved. Because of the intense radioactivity of SNFs now in storage, material accountancy involving independent estimation of the SNM contents of SNFs appears to offer limited prospects in maintaining safeguards for spent fuels in long-term storage and during consolidation. Presently, it is very difficult for a regulatory agency to have verified knowledge of SNM contents of spent fuels. Also, verifying how much SNM is actually present may not serve useful safeguards purposes. Verification of fuel bundle integrity by NDA measurement or other means may have useful safeguards relevance.

VI. PRAGMATIC ALTERNATIVES

The introduction of safeguards for radioactive waste materials, especially large quantities of spent nuclear fuels, is going to create an enormous burden for present safeguards systems. Because these material forms and disposal scenarios were not part of the early safeguards regime development, there is a need to objectively examine the safeguards requirements of the waste materials and arrive at some pragmatic approaches to addressing the problems. Some of the possibilities are as follows.

1. For HLWs and TRU wastes, a verification system to estimate the SNM contents of waste materials being transferred to final processing for permanent disposal ought to be considered. This approach would not only confirm some of the present estimates but deter diversion of other forms of SNM through waste materials leaving storage locations. Attempts to estimate SNM contents of HLWs and TRU wastes may also help to rectify some of the very large cumulative IDs of SNM at the facilities and potentially identify waste matrices that may lend them

selves to economic recovery of SNM that has been improperly discarded.

2. Containment and surveillance measures for processed wastes during their residence at storage facilities and transit to permanent repositories is probably the least expensive safeguards measure for these waste forms.

3. A separate graded safeguards regime for spent nuclear fuels based on a properly defined attractiveness level based on, among other things, burnup and decay time may save considerable resources for both nuclear facilities and regulatory agencies.

4. An upward modification of "goal quantity" and "timeliness" for detecting SNM from all waste forms discussed here along with graded safeguards for SNFs can go a long way in maximizing the use of safeguards resources.

5. Encouraging the development of a spent fuel management regime, wherein there will be a safeguards system that can primarily rely on containment and surveillance rather than quantitative measurements of fissile contents of spent fuels, would have considerable practical value.

Developing strategies, systems, and necessary technologies for safeguarding SNM contained in radioactive waste forms are challenges facing the safeguards community. A variety of safeguards measures can be adapted, and additional new technologies may be required to maintain a satisfactory safeguards regime for these radioactive waste forms to prevent their diversion and use as media for planned diversions.

VII. CONCLUSIONS

The data presented in this paper are based on present knowledge of inventories of SNM in wastes in the US. The data should be viewed in the context of waste matrices in which they are distributed although the totals are likely to attract attention. The spent fuels in the US are likely to become a candidate for international safeguards. The high-level wastes when placed in the same repository as spent fuels may have some international safeguards relevance. The TRU wastes in the US will be totally out of the international safeguards regimes. All the wastes in the US containing fissile materials are presently in secure storage locations and some of them are discards from domestic safeguards. During the last decade, waste management programs in the US have evolved to a stage where good accounting of waste streams are routinely done as part of good nuclear materials management. Because it is very difficult to extrapolate present practices to accumulated inventories of the past, it would be prudent to examine the issues presented here in proper context and proceed to develop strategies and systems for good materials management practices that will also contribute positively to environmental safety, public concern over radioactive waste disposal, and good nuclear material safeguards.

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